Biological Report 90(17)
December 1990

Ninety Years of Salmon Culture at Little White Salmon National Fish Hatchery

Fish and Wildlife Service
U.S. Department of the Interior

Biological Report

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ISSN 0895-1926

This publication may be cited as:

Nelson, William R., and Jack Bodle. 1990. **Ninety Years of Salmon Culture at Little White Salmon National Fish Hatchery.** U.S. Fish Wildl. Serv., *Biol. Rep.* 90(17). 22 pp.

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Abstract. The Little White Salmon National Fish Hatchery was built in 1896 to supplement the run of tule fall chinook salmon (*Oncorhynchus tshawytscha*). In succeeding years other species of salmon and trout were reared but coho salmon (*O. kisutch*) was the only species that established a dependable run. The fall chinook salmon egg take peaked at over 40 million in 1917, and the release of juveniles peaked at nearly 24 million in 1914. Fish were released as unfed fry until 1908, when increasing numbers were reared for later release. Construction of Bonneville Dam in 1938 severely disrupted hatchery operations by flooding the hatchery, and diseases were not a problem until the 1950's.

From the 1917 peak of 40 million, the fall chinook salmon egg take declined to a low of about 1.7 million in 1944 before recovering to nearly 30 million in 1958. In response to a generally declining and highly variable egg take after 1958, increasing numbers of eggs were obtained from other sources; after 1968, more than 50% of the fish released were not native. By 1985, the native tule fall chinook salmon run was so depressed that rearing this stock was abandoned. Although the construction of Bonneville Dam had a deleterious effect on production and survival, the importation of stocks (which changed their genetic fitness and introduced diseases) and rearing fish longer (which reduced survival in the hatchery) were contributing factors. Therefore, after 90 years of rearing a native stock originally described as so abundant that the spawners filled the river for a month, efforts are now dedicated to rearing transplanted fall and spring chinook salmon stocks.

Key words: Salmonidae, anadromous, Columbia River, fish culture.

In summer 1896, Professor B. W. Evermann and W. F. Hubbard, superintendent of the Clackamas State Fish Hatchery, Oregon, examined some Columbia River tributaries with the intent of establishing a Federal salmon hatchery (Ravenel 1898). According to Evermann and Meek (1898), there were four criteria used in selecting the hatchery site: (1) An abundant supply of salmon easily obtainable when ripe or nearly ripe; (2) a sufficient quantity of water of proper purity and temperature; (3) suitable land upon which to locate the hatchery building and situated to permit water to be brought to the hatching troughs by gravity; and (4) proximity of building materials and good railroad facilities.

They selected the Little White Salmon River because they believed it was one of the principal spawning grounds for quinnat (chinook) salmon (*Oncorhynchus tshawytscha*). On 5 September 1896, construction of the hatchery, mess house, and a rack across the river was begun; on 26 September, collection of eggs began. Spawning continued until 14 October, when 2,179,000 eggs had been collected. As the work had not started until late in the season, these results were considered excellent. In addition, Ravenal's (1898) observation that "During the season, the salmon appeared in such large numbers below the rack that the Indians often speared two and three at one cast of the spear" augured well for the future of this site. Thus, the Little White Salmon River became the site of the third hatchery on the Columbia River and today is the fifth oldest U.S. Fish and Wildlife Service hatchery in the Nation.

Artificial propagation of Pacific salmonids began in 1872 on the McCloud River, a tributary of the Sacramento River in California (Cobb 1911; Wahle and Vreeland 1979). The purpose of these efforts was to introduce salmon into rivers in the Eastern States, where Pacific salmon (*Oncorhynchus* spp.) "exceed all other species which are propagated, in hardiness, in tenacity of life, and in freedom from tendency to disease" (U.S. Commission of Fish and Fisheries 1876).

The first salmon hatchery in the Columbia River basin was built in 1876 by the Oregon and Washington Fish Propagating Company on the Clackamas River, Oregon. This facility, with a capacity of 6 million eggs, was purchased in 1888 by the U.S. Commission of Fish and Fisheries for $5,155.60 (Rathbun 1892). By then, however, the impetus for artificial propagation had shifted from introducing salmon into eastern river systems to maintaining existing population levels; commercial landings of chinook salmon in the Columbia River had declined from about 19.5 million kilograms in 1883 to 8.2 million kilograms in 1889 (Beiningen 1976). Collins (1892) commented

> No section of the country is probably more dependent on fish-culture for the successful continuance of its fisheries than the Pacific slope. Experience has fully demonstrated that the supply of salmon is likely to be so much reduced through overfishing that the industry depending upon their capture must soon be abandoned, unless the skill and well directed efforts of man are utilized to maintain the stock upon which he draws so heavily and so continuously. Artificial propagation of fish has now passed beyond the experimental stage, and there is no longer doubt in unprejudiced and well-informed minds as to its possibilities when conducted intelligently and on a scale equal to the objects aimed at. It is believed by those competent to speak on the subject that the artificial propagation of salmon has been very beneficial of late on the Columbia River, although the hatchery on the Clackamas has not been long established and the magnitude of its operations has not, until quite recently, been commensurate with the important interests at stake.

Although these conclusions would be viewed with considerable skepticism today, they led to a rapid expansion of artificial production near the turn of the twentieth century. By 1904 more than 71 million chinook salmon were released in the Columbia River; by 1987 more than 190 million salmon and steelhead (*Onchorhynchus mykiss*) were released in the basin from 64 hatcheries and 29 satellite facilities (Columbia Basin Fish and Wildlife Authority 1988).

This report is documentation of the changes in fish culture objectives, methods, and stocks during the past 90 years by presenting the history of the Little White Salmon National Fish Hatchery (NFH). Primary sources of data include the daily logs since July 1914, egg-take records since 1913 (except for 1928–48), production records from 1913, and annual reports from 1940.

Description of the Area

The Little White Salmon River drains about 347 km^2 of the Cascade Mountains in south-central Washington before joining the Columbia

River at river km 261. The river—the principal source of water for the hatchery—has a mean annual discharge of about 560 cfs (cubic feet per second), and a range from 100 cfs (October) to 9,000 cfs (January; U.S. Geological Survey 1978). About 2.9 km above its confluence with the Columbia River is a barrier to upstream migration of salmonids. Although the hatchery was built on this river because of the run of chinook salmon, chum salmon (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) were also present (Bryant 1949). The chinook stock in the Little White Salmon River was the fall spawning stock of tule, a lower river stock that spawns from mid-September through mid-October. The eggs hatch from mid-November through December. On emergence from the gravel, the juveniles gradually migrate downstream, entering the ocean in their first year. Therefore, the fact that <3 km of river was available for rearing had minimal effect on the rearing of native stocks of chinook and chum salmon but undoubtedly severely limited coho salmon production.

Early Years—1896–1915

The original hatchery was described in Ravenel (1898) as follows:

> ...a rough wooden structure without a floor, lighted by skylights above and unglazed windows in the sides and ends. It was equipped with 50 troughs, and the water supply was obtained from a brook a short distance away. The other buildings consisted of sleeping quarters and a mess-house for the employees. At the close of the collecting season the trough room was found to be insufficient, and additional troughs were erected outside for holding the fry. ... At the close of the season the apparatus was stored in the bunk-house and, as the grounds on which the station is located are liable to floods, the hatchery was weighted down with stone and placed in charge of a watchman, who was permitted to occupy the mess-house.

The cost for constructing and operating the hatchery this first season was $2,288.27.

On reopening the hatchery 20 July 1897, it was found that flooding by the Columbia River had floated the hatchery off its foundation. After flood damage was repaired, another hatchery building was constructed:

> ... a substantial structure of wood, 42 feet by 80 feet, and is so arranged that the roof is supported by the sides of the building, thereby leaving the entire floor space free of posts and giving more room for hatching operations. The floor is terraced uniformly from one end of the building in four sections, with a difference of 8 inches in elevation from one section to the next. On each of these a row of troughs runs length-wise of the building, the troughs in each maintaining an elevation of 8 inches above those in the next, in conformity with the plan of the floor. They are fed with water conducted by a flume to a supply-trough placed against the end-wall. By this arrangement all of the troughs are at a uniform height from the floor, and the manipulation of eggs is much easier than where troughs of different heights are set upon a level. The building is lighted by skylights in the roof and by windows in the sides and ends (Ravenel 1899).

In 1898, a third hatchery building was constructed (Ravenel 1901). It was 30.5 × 12.2 m and contained 80 troughs of 4.9 × 0.4 m. Records are minimal from 1901 to 1915; apparently, however, there was no additional major construction.

Ravenel (1900) described the methods of capturing the adults, spawning, and care of the eggs:

> The fish are captured by means of a downstream trap, which consists of a box about 20 feet long by 8 feet wide and 18 inches deep, made of slats placed 2 inches apart, anchored in midstream. The end of the trap pointing upstream is weighted to the bottom of the river and a dam or rack extends from its two sides to within a few feet of either bank. The fish ascending the stream pass around the rack to the spawning-grounds above, and as soon as sufficient number have collected a seine is drawn downstream at a rapid rate. Although salmon always swim against the current, when frightened they turn and go rapidly downstream, and as a consequence they are brought to a halt high and dry upon the lower end of the trap. They are then quickly assorted and placed in pens near the traps, the males and females being put in separate compartments. Most of the fishing during the season is done at night, the best hauls being usually made about an hour after dark.
>
> Spawning operations commence in the morning and continue until all ripe fish have been stripped. The female is first taken from the pen by the spawn-taker, and if found to be ripe she is killed by striking her upon the back of the head with a club. She is then placed in the spawning-box, which is raised to a vertical position so that the

eggs may be stripped into a pan held by an assistant. As soon as the milt is added to the eggs the contents are gently stirred until every egg has come in contact with it. A little water is then added and the pan placed aside for 1 1/2 minutes, when it is handed to a third person, who washes the milt and dirt from the eggs by immersing the pan in water. The eggs are then carried in buckets to the hatchery, measured, and placed in baskets. The buckets hold about 15,000 eggs each, and are carried in pairs by means of yokes, one man carrying two buckets. The baskets to which they are transferred on arriving at the hatchery hold from 25,000 to 40,000 each, depending on the size of the troughs used. After being placed in the troughs they are covered to exclude the light. On the first, second, and third days the dead eggs are picked off, after which they are not uncovered for at least 30 days, provided the water is clear. At the expiration of this period they are placed in water-buckets and a strong current of water turned on, which causes all of the unimpregnated eggs to turn white, while it does not injure the good ones. After the dead eggs have been removed the remainder are returned to the baskets.

Before 1908, all fish were released as fry, and the hatchery was closed by 1 March. In 1908, however, some fish were reared for an extended period. Initially fed finely ground beef liver, they were then switched to either salmon or eulachon (*Thaleichthys pacificus*). After spawning, the salmon carcasses were skinned, split, boned, and stored in tanks or barrels containing salt brine (O'Malley 1921). When needed, the carcasses were soaked in running water overnight to remove the salt, cooked, pressed into cakes, and grated to the desired size. The eulachon were obtained as they were needed from commercial processors during the spring spawning run. These fish were frozen when received, and later cooked, pressed into cakes, and grated to the desired size (O'Malley 1921).

Fall Chinook Salmon

Fall chinook salmon were initially the only species propagated. Available data indicate that spawning extended from about mid-September to mid-October, and the average number of eggs taken was more than 16.5 million (Table 1). Large numbers of eggs were shipped to other hatcheries, such as Clackamas (1898, 1899, 1900, and 1913 brood

Table 1. *Fall chinook salmon* (Oncorhynchus tshawytscha) *spawning and production at Little White Salmon National Fish Hatchery, 1896–1915.*

Brood year	Spawning			Eggs transferred		Fish released into			Survival
	Start	End	Egg take	Shipped	Received	Little White Salmon River	Various[a]	Total	(%)
1896	26 September	14 October	2,179,000			1,848,760		1,848,760	85
1897	12 September	6 October	12,649,000			7,391,000		7,391,000	58
1898	11 September	3 October	7,176,000	4,926,000		1,791,000		1,791,000	80
1899	11 September	10 October	10,385,000	2,686,000		5,630,947	996,000	6,626,947	86
1900	12 September		12,840,700	4,955,000		1,653,000	3,772,680	5,425,680	69
1901			14,166,132		1,171,868	8,398,305	3,682,500	12,080,805	79
1902						3,890,500	8,186,500	12,077,000	
1903				5,287,000		10,426,000		10,426,000	
1904						2,138,500		2,138,500	
1905						828,100	7,212,000	8,040,100	
1906				1,100,000		1,934,450	2,350,000	4,284,450	
1907			10,176,000	1,485,000		4,929,800	3,220,000	8,149,800	94
1908			9,558,000	3,050,000		5,941,186		5,941,186	91
1909			8,998,000	3,805,000		4,808,000		4,808,000	93
1910			10,696,000						
1911			14,912,000	8,000,000		5,118,095		5,118,095	74
1912			30,595,000	19,713,000		5,403,000		5,403,000	50
1913	19 September	30 October	34,183,000	20,876,000		12,405,757		12,405,757	93
1914	20 September	13 October	35,787,000	11,607,000		23,216,957		23,216,957	96
1915	19 September	12 October	34,386,000	9,186,000		23,812,071		23,812,071	94
Mean	15 September	13 October	16,578,522	4,081,294	78,125	6,924,496	1,548,404	8,472,900	82

[a] Released in Columbia River or nearby tributaries.

years) and Bonneville (1909, 1911–12 brood years) in Oregon and Big White Salmon (1912–15 brood years) in Washington. Eggs were also shipped to the Oregon (1900, 1906–08 brood years) and Washington (1914 brood year) fish commissions for distribution to other hatcheries; in 1899, 250,000 eggs were shipped to New Zealand. The only eggs received during this period were from the nearby Big White Salmon River in Washington and Eagle Creek in Oregon in 1901.

From 1896 to 1915, nearly 8.5 million fish were produced annually; more than 6.9 million were released in the Little White Salmon River, and the remaining fish were released in the Columbia River or nearby tributaries (Table 1). In 1908, about 580,000 fish of the 1907 brood year were classified as fingerlings at release (U.S. Bureau of Fisheries 1910). The vast majority of each year's production continued to be released as fry, but some fish were retained and reared in hatching troughs. Survival from egg take to release was variable and averaged 82%. No particular problems were mentioned in the annual reports to account for this low survival.

Middle Years—1916–1964

The potential for rearing juvenile salmonids was greatly increased with the construction of 20 concrete rearing ponds in 1916 and 4 earthen ponds in 1921. In 1922, the original hatchery buildings were torn down, and a new building (12.2 × 42.7 m) was constructed. This new building included 128 hatchery troughs and provided space for incubating 30 million eggs. In 1929, a 63.5-metric-ton-capacity cold storage building was constructed, but electricity was not available until June 1931. The closure in 1938 of Bonneville Dam, located about 25.7 km downstream, resulted in the Columbia River inundating all these facilities. Therefore, another hatchery building was constructed in 1939, but rearing facilities were not available for another 8 years. In 1947, six ponds (24.4 × 2.4 × 1.2 m) were constructed, as were a fish ladder and adult holding pond (45.7 × 6.1 × 1.2 m). In 1950, 15 additional rearing ponds were built, and the fish ladder and adult holding pond were extended and modified to increase efficiency and holding capacity.

Until 1947, the adult salmon had been collected by placing a wooden rack across the river. Construction of the fish ladder and holding ponds was a major change in fish culture, allowing the adults to independently ascend the ladder into the holding pond, greatly reducing the number of times brood fish were handled.

Spawning practices did not change until 1963, when adults were anesthetized with tricaine methanesulfonate (MS-222) to facilitate handling. The eggs were incubated in baskets placed in a wooden trough that was baffled to provide water upwelling through each basket. Incubation in baskets continued until the eyed stage (about 30 days), when the eggs were shocked by (1) vigorous stirring, (2) siphoning from basket to bucket, or (3) pouring from basket to basket. Dead eggs were floated using a salt solution and skimmed off or hand picked.

Before 1935, the live eyed eggs were returned to the wooden troughs in baskets made of screen material large enough to allow the newly hatched fry to drop through the bottom screen into the trough. The fry were then either released immediately as sac fry, allowed to absorb their yolk sac and then released as "buttoned up" fry, or placed in ponds and reared to fingerling size. After 1935, the live eggs were placed on trays, 2,000 per tray, with 15 trays per stack. Each trough held 10 stacks, or 300,000 eyed eggs. The eggs were allowed to hatch, and the fry remained in the stacks until they absorbed their yolk sacs and were ready to go on feed or be released from the hatchery.

The feeding and rearing of fry to fingerling size expanded after construction of 20 ponds in 1916. The diet consisted of liver (horse, beef, or pork) and salmon carcasses. The production level of 7–13 million fingerlings remained constant until 1938, when closure of Bonneville Dam flooded the production facilities. During 1938–40, fish were not fed but were released as fry. From 1941 to 1947, about 400,000 fish were fed and released as fingerlings and the remaining production planted as fry. The diet was composed of 30% beef liver, 30% horse meat, 20% salmon viscera, and 20% beef spleen; salt was used as a binder.

Major construction from 1947 to 1953 changed fish culture practices. A concrete adult pond was constructed, as were 33 concrete ponds of 24.4 × 2.4 m with related water supply and discharge systems. In 1950, fry were stocked in the new ponds at the rate of about 90 kg/pond and reared until release. In 1952, fish were stocked at the rate of 225 kg/pond and reared until they reached about 400–450 kg/pond, when a release was made, reducing the weight to about 270 kg. Fish in excess of 270 kg/pond were released throughout the season. Each pond produced about

1,135 kg by July. Rearing-pond water flowed at 450 gpm (gallons per minute). Fish were fed a diet of 50% liver and 50% fish eggs three times per day for the first 2 weeks, then a diet of 33% liver, 33% eggs, and 33% salmon carcasses; wheat middlings were added up to 5% of the diet. The first dry commercial diet, Clark's Chinook Feed, was tried in 1958; it did not achieve the same results as the standard wet production diet, which continued unchanged except that turbot or herring (*Clupea harengus*) was substituted for salmon carcasses. After the fish were started on the production wet diet, Oregon Moist Pellet (OMP) diet was fed to coho salmon on a trial basis in 1962. In 1963, the OMP diet was determined adequate for coho and chinook salmon over the entire feeding range. By 1964, all fish were fed commercial diets. Clark's Chinook Mash was used to start fry on feed; when they reached about 1,550/kg, the diet was changed to OMP.

Fall Chinook Salmon

Figure 1 illustrates the consistency of fall chinook salmon spawning time. In 43 of 49 years, spawning began between 18 and 22 September. Its completion was more variable, occurring between 2 October and 4 November. In 1925, 1927, and 1932, spawning ended early because egg requirements had been met.

Annual egg takes ranged from 1,685,000 in 1944 to 40.4 million in 1917 and averaged nearly 16.3 million (Table 2). Before the closure of Bonneville Dam in 1938, however, the average was about 21.19 million compared with 11.94 million after 1938. In only 7 of the 23 years before 1938 was the egg take below the overall average, whereas the egg take after 1938 was below average 21 of 26 years. An above-average egg take in 1952 was attributed to a commercial fishermen's strike and to a delayed season opening in 1958 (Cox 1959). In the late 1950's, egg takes would have been larger were it not for bad eggs in about 15% of the females as a result of mycobacteriosis, caused by raw salmon products in the diet (Cox 1960; Ross 1970).

Before 1938, about 8.66 million eggs were transferred annually to other locations; after 1938, this figure declined to about 1.825 million (Table 2). Eggs were shipped to California, Illinois, Kentucky, Massachusetts, Montana, Nevada, New Hampshire, New York, Utah, Vermont, and Washington (D.C.), as well as to various sites in Idaho, Oregon, and Washington. In 1955, about 16,700 eggs were shipped to Madagascar. Far fewer eggs were received than shipped, but the number and frequency of eggs received increased dramatically after 1938 with the closure of Bonneville Dam. Eggs were received in 1922 from the Kalama River and in 1926 from the Wind River; all later shipments were from the Big White Salmon River. Therefore, all the eggs received, except for those from the Kalama River, were from what is now considered the Bonneville Pool Hatchery Stock (Howell et al. 1984).

The time of juvenile release was highly variable but tended to occur later as the years went by (Fig. 2). Initial releases occurred as early as 19 December in 1917 and as late as 29 August in 1930. Final releases were completed as early as 23 February in 1938, when filling of Bonneville Reservoir flooded the ponds, and as late as 29 May in 1957, when fish of the 1955 brood year were released as yearlings rather than the normal age-0. Holding a portion of the year's production for release as year-

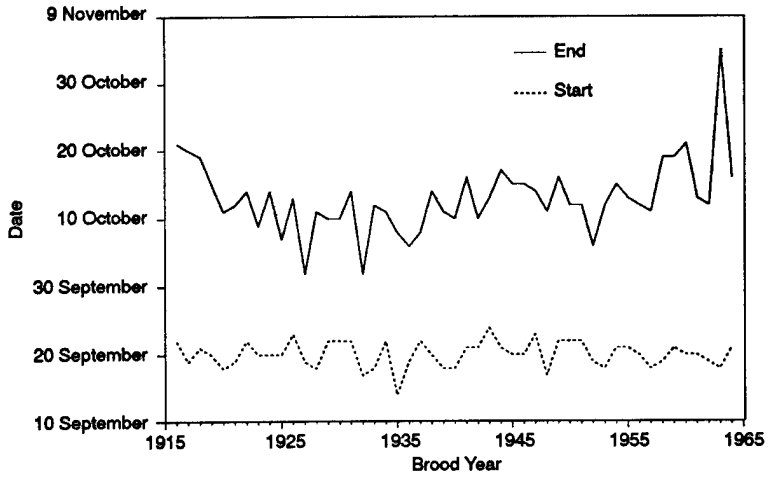

Fig. 1. Spawning time of fall chinook salmon at Little White Salmon National Fish Hatchery, 1916–64.

Table 2. *Fall chinook salmon spawning* (Oncorhynchus tshawytscha) *and production at the Little White Salmon National Fish Hatchery, 1916–64.*

Brood year	Egg take	Eggs transferred		Fish released				Survival (%)
		Shipped	Received	Number/kg[a]	Little White Salmon River	Various	Total	
1916	17,848,000	2,300,000		1,719	14,865,775		14,865,775	95
1917	40,400,000	16,865,000		1,669	22,054,075		22,054,075	94
1918	10,693,000	960,000		570	9,177,000		9,177,000	94
1919	19,819,00	5,958,000		562	12,150,800		12,150,800	94
1920	16,590,000	4,050,000		557	11,990,000	200,000	12,190,000	97
1921	33,640,000	8,050,000		603	24,582,000		24,582,000	96
1922	14,005,000	5,975,000	5,000,000	626	12,427,000		12,427,000	95
1923	14,415,000	2,372,000		583	11,394,000		11,394,000	95
1924	22,460,000	6,582,000		715	15,047,000		15,047,000	95
1925	29,484,000	14,369,000		763	14,723,000		14,723,000	94
1926	26,505,000	12,185,000	750,000	813	13,829,000		13,829,000	92
1927	26,600,000	14,783,560		748	8,700,000		8,700,000	74
1928	20,172,000	9,223,000			9,940,000		9,940,000	91
1929	9,930,000	1,752,000			2,500,000		2,500,000	
1930	24,880,000	12,718,000		701	16,375,000		16,375,000	
1931	22,785,000	12,185,000		2,299	9,680,000		9,680,000	88
1932	26,705,000	4,410,000		1,057	20,832,000	155,000	20,987,000	94
1933	15,860,000	7,525,000		863	7,841,181		7,841,181	94
1934	4,010,000			1,389	3,807,000		3,807,000	95
1935	37,855,000	24,970,000		1,715	10,034,335	1,000,000	11,034,335	70
1936	23,670,000	12,275,000		881	8,713,000		8,713,000	93
1937	8,640,000	3,000,000		2,103	5,376,000		5,376,000	95
1938	20,443,000	7,978,000		1,581	10,966,000		10,966,000	88
1939	12,225,000	300,000		2,103	11,343,000		11,343,000	95
1940	12,975,000			2,002	12,407,000		12,407,000	96
1941	7,550,000		3,000,000	1,863	10,028,560	149,000	10,177,560	96
1942	14,475,000	6,600,000	8,683,000	2,059	11,433,577		11,433,577	79
1943	2,785,000			1,512	2,668,114		2,668,114	96
1944	1,685,000			1,326	1,533,900		1,533,900	91
1945	4,562,000			1,576	3,975,544		3,975,544	87
1946	5,870,000	875,000	920,000	1,681	5,327,400		5,327,400	91
1947	8,670,000		769,200	974	6,703,632		6,703,632	71
1948	15,402,800	774,000		2,199	13,412,260		13,412,260	92
1949	4,532,440		7,430,515	1,023	8,712,058	1,057,080	9,769,138	82
1950	11,592,265	2,625,000	4,965,050	590	10,430,873	42,455	10,473,328	75
1951	21,788,635	5,086,265		698	15,110,297	315,882	15,426,179	92
1952	25,074,760	8,279,160		698	15,746,946		15,746,946	94
1953	9,933,420	30,000		377	8,987,843	7,900	8,995,743	91
1954	8,100,550	2,015,000		179	5,702,493		5,702,493	92
1955	5,457,200	57,867		230	6,399,751	89,890	6,489,641	
1956	6,788,005	500,000	1,500,000	721	6,737,445		6,737,445	87
1957	18,605,338	5,500,239	581,744	796	12,448,925	237,160	12,686,085	91
1958	29,523,170	8,264,638		789	19,318,015	66,717	19,384,732	90
1959	23,133,215	974,000	625,540	1,219	13,364,007	7,039,760	20,403,767	90
1960	8,602,350	45,600		436	7,511,018	4,470,200	11,981,218	88
1961	14,419,045	100,410		424	12,880,118	4,150	12,884,268	90
1962	12,018,592	10,000		476	11,026,390	20,000	11,046,390	92
1963	11,063,215	135,000	5,387,000	473	12,794,744	20,000	12,814,744	79
1964	13,671,000	5,226,750	7,159,250	428	9,152,200		9,152,200	59
Mean	16,283,918	5,802,061	2,923,206	1,050	10,860,414	303,575	11,163,989	89

[a] Estimated from length data for 1916–40 brood years and weight data for 1941–64 brood years.

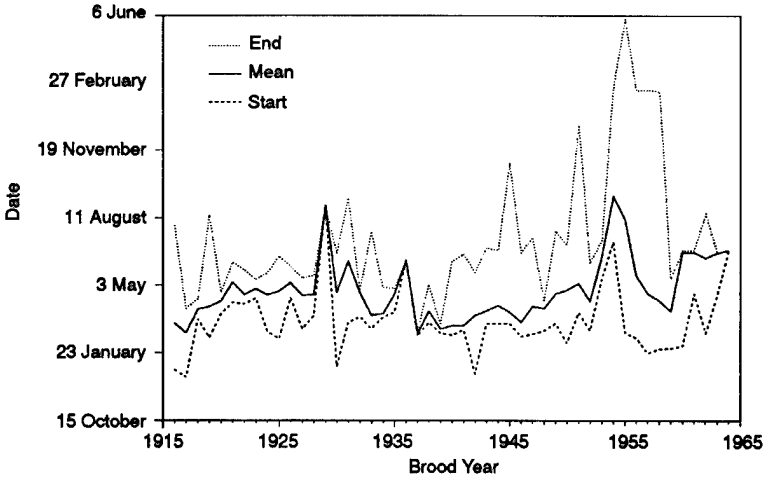

Fig. 2. Average time of release of juvenile fall chinook salmon from the Little White Salmon National Fish Hatchery, 1916–64.

lings continued for the 1954–58 brood years and was part of a study to determine the optimum size and time of release. Marked fish were usually released in May, July, September, October, and February and exhibited average escapements of 0.11, 0.26, 0.03, 0.16, and 0.41 fish per 1,000 released, respectively. In 1960, however, mid-June was selected as the time for releasing the majority of the annual production to coincide with expected maximum river flows (H. Johnson, retired, U.S. Fish and Wildlife Service, Cook, Washington, personal communication).

As would be expected, the variability in time of release resulted in variable size at release (Table 2 [Before 1941, fish were classified at release by length rather than weight, and weights were estimated on the basis of these lengths.]) During the 1930's, the disruption caused by the construction of Bonneville Dam probably resulted in much of the variability in size. During the 1940's, the lack of rearing space resulted in relatively small fish being released. The variability in size at release during the 1950's was a function of the time-of-release study; the size did not stabilize until the 1960's.

With the exception of brood years 1943–47, production was relatively consistent (Table 2). Because of incomplete records in 1929 and 1930, some unknown portion of the 1929 brood was credited to the 1930 brood. The numbers of fish produced at the Little White Salmon NFH and released elsewhere increased with time. The first large release was made in the Wind River in 1936, followed by large releases of the 1949 brood year fish in the Klickatat and Washougal rivers. The large releases of the 1959 and 1960 brood years were transfers to the newly constructed Willard NFH (located about 4.8 km upstream on the Little White Salmon River), which were subsequently released back into the parent stream. In fact, after 1941, substantial numbers of fish native to the Big White Salmon and Washougal rivers were reared at the Little White Salmon and Willard hatcheries for release in the Little White Salmon River (Table 3). All fish released before 1941 in the Little White Salmon River were native to that river, with the possible exceptions of fish from the Big White Salmon River and Eagle Creek (1901 brood year), Kalama River (1922 brood year), and Wind River (1926 brood year). After 1941, about 20% of the fish released in the Little White Salmon River were from stock not native to the river, and in 1955 and 1956, >45% of the total fish released were not native to the system. In addition to the fish released from Little White Salmon NFH, an average of >4,340,700 fish reared at Willard NFH were released in the Little White Salmon River.

Survival from egg collection to juvenile release was high (Table 2). In the early years, only the 1927 and 1935 brood years had poor survival rates. The daily log entry for 11 March 1928 (brood year 1927) indicated that floodwaters of the Little White Salmon River inundated two rearing ponds, allowing an unknown number of fish to escape. The daily log entry for 11 May 1936 (brood year 1935) mentions fish dying in the ponds and reports treating the fish with a salt bath intermittently until 25 June; fish were released on 29 June. In December 1942, the daily logs repeatedly mentioned problems of sediment on the eggs, caused by turbid floodwaters, and the hatching success was poor. The first reference to above-normal egg loss was in 1947; excessive handling during spawning was given as the reason (Evenson 1948). On 6 October 1949, the daily log entry stated, "It was discovered

Table 3. *Fall chinook salmon* (Oncorhynchus tshawytscha) *from the Little White Salmon, Big White Salmon, and Washougal rivers, produced at the Little White Salmon (LWS) and Willard national fish hatcheries (NFH) and released in the Little White Salmon River, 1941–64.*

Brood year	Little White Salmon		Big White Salmon		Washougal	Total
	Little White Salmon NFH	Willard NFH	Little White Salmon NFH	Willard NFH	Willard NFH	
1941	7,297,560		2,731,000			10,028,560
1947	6,157,500		546,132			6,703,632
1948	13,412,260					13,412,260
1949	3,716,600		4,995,458			8,712,058
1950	8,524,576		1,906,297			10,430,873
1951	15,110,297					15,110,297
1952	15,746,946			10,107,332		25,854,278
1953	8,987,843			7,472,385		16,460,228
1954	5,579,908	1,601,169	122,585	3,518,023		10,821,685
1955	6,399,751			2,621,441		9,021,192
1956	5,867,445		870,000	4,070,088		10,807,533
1957	11,919,538		529,387	4,849,676		17,298,601
1958	19,318,015	2,695,619		7,765,583		29,779,217
1959	13,364,007	6,295,908				19,659,915
1960	7,511,018			4,337,520		11,848,538
1961	12,880,118			100,162		12,980,280
1962	11,026,390				994,597	12,794,744
1963	8,573,474		4,221,270			
1964	7,512,500		1,639,70			9,152,200

that the water is supersaturated with nitrogen which causes explosions in the stacks. This in turn causes heavy egg loss."

In 1950, poor quality feed containing excessive amounts of fish tails and fins and insufficient quantities of eggs was believed to be the cause of slow and continuous juvenile mortality (Cox 1951). Abnormally large mortalities in 1964 were believed to be caused by inexperience concerning first use of OMP, rather than disease. In fact, diseases were not considered a problem, and it was 1952 before a specific disease problem—loss of fry from coagulated yolk disease—was reported (Cox 1953). Problems with disease increased during the 1950's, when fish were reared for longer periods during the time-of-release study. Coagulated yolk disease continued to be a problem, and bacterial kidney disease (*Renibacterium salmoninarus*) was diagnosed in 1958 after first appearing in coho salmon 2 years earlier (Cox 1959).

A stock–recruitment curve was calculated on the assumption that adult return was divided equally among 3- and 4-year-old fish. This indicated that as the years progressed it became less common for a brood year to maintain itself (Fig. 3). Before the closure of Bonneville Dam in 1938, all broods maintained themselves, whereas after the closure, 12 of 26 broods failed. The poor return of the 1939–42 brood years was probably a result of their release as unfed fry. There was no significant correlation between the stock–recruitment ratios and estimates of harvest or escapement in the Columbia River from 1930 to 1964 ($r = 0.189$ and 0.21, respectively; $P > 0.05$; Beiningen 1976).

Chum Salmon

Chum salmon production began in 1916. Native fish were used for brood stock until 1934, when the run began to fail (Table 4). From 1947 to 1954, attempts were made to reestablish a run by importing eggs and fry from the Quilcene River, a tributary to Puget Sound, Washington. A few adults returned from 1959 to 1963, but the production of chum salmon was then abandoned.

Spawning of the native stock usually began in late October or early November and was completed by mid-November to early December, whereas spawning of the introduced Quilcene stock took place about 2 weeks later (Table 4). The egg take from the native stock averaged about 635,000 from 1916 to 1954, whereas the maximum egg take from the introduced stock was 42,000 in 1963; from 1928 to 1951, the egg

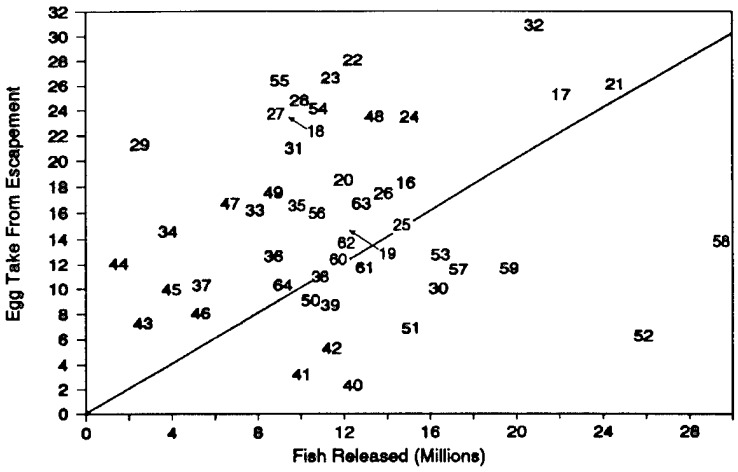

Fig. 3. Stock–recruitment of fall chinook salmon to Little White Salmon National Fish Hatchery, 1916–64.

Table 4. *Chum salmon* (Oncorhynchus keta) *spawning and production at Little White Salmon National Fish Hatchery, 1916–64.*

Brood year	Spawning			Eggs transferred		Fish released		
	Start	End	Egg take	Shipped	Received	Date	Little White Salmon River	Survival (%)
1916	30 October	24 November	1,893,100				1,695,450	90
1917								
1918	2 November	18 November	515,000			13 April 1919	460,800	89
1919	13 November	2 December	204,000			26 April 1920	183,150	90
1920	28 October	22 November	5,162,000			29 March 1921	5,067,900	98
1921								
1922	4 November	20 November	285,000			5 April 1923	257,500	90
1923	2 November	20 November	414,000			27 March 1924	379,000	92
1924								
1925								
1926								
1927								
1928[c]	25 October	21 November	840,000	765,000			49,000	65
1929	30 October	21 November	505,000	35,000		18 April 1933	403,000	86
1930	10 November	17 November	375,000	50,000			345,000	
1931	28 October	10 November	1,358,000	425,000			863,000	92
1932								
1933	1 November	14 November	302,000				286,500	95
1934	1 November	20 November	206,000				199,000	97
1947[a,c]					250,380	28 April 1948	242,760	97
1948								
1949								
1950					500,220	19 April 1951	490,625	98
1951					958,750	24 April 1952	949,450	99
1952					101,760[b]	18 May 1953	100,925	
1953					500,000	12 April 1954	498,000	100
1954					379,056[b]	16 July 1955	302,194	
1959[a,c]	1 December	10 December	28,600			28 March 1960	23,120	81
1960	14 November	9 December	11,200			6 March 1961	8,624	77
1961								
1962	13 November	27 November	39,850			25 March 1963	38,215	96
1963	2 November	9 December	42,000			28 March 1964	40,450	96
Mean	4 November	24 November	248,587	26,020	54,901	16 April	262,932	91

[a] No spawning for years 1935–46 or 1955–58.
[b] Fry received.
[c] No production for years 1924–27, 1935–46, or 1955–58.

take was sufficient to ship excess eggs to the Oregon Fish Commission.

All chum salmon reared were released in the Little White Salmon River. Fish were usually released at the start of feeding at a size of <2,200/kg, but in 1953 and 1955 they were reared to about 925/kg. This early release resulted in survival exceeding 91% from egg take to release.

Sockeye Salmon

Attempts to establish a sockeye salmon (*Oncorhynchus nerka*) run began in 1918, when >1 million eggs were received from Yes Bay, Alaska (Table 5). This first shipment of eggs was followed by shipments from Birdsview (1920 and 1932 brood years), Quinault (1929 brood year), and Leavenworth (1951 and 1952 brood years), Washington. From these shipments, small and sporadic returns of adults to the Little White Salmon River were established.

The majority of the juveniles were released in their first spring (Table 5). However, about 8% of the 1918 brood and all of the 1920 brood were held for an additional year of growth. All remaining fish were released in their first year until March

Table 5. *Sockeye salmon* (Oncorhynchus nerka) *spawning and production at Little White Salmon National Fish Hatchery, 1916–64.*

Brood year	Spawning		Egg take	Eggs received	Released				Survival (%)
	Start	End			Date	Number /kg	Little White Salmon River	Various	
1918				1,059,900	8 July 1919		1,019,575		96
1919									
1920				30,000	15 February 1922		26,365		88
1921									
1922	28 September	9 October	56,000		14 April 1923		50,400		90
1923									
1924									
1925									
1926	23 September	7 October	60,000		26 June 1927		46,500		78
1927									
1928									
1929				50,000			40,500		81
1930									
1931									
1932	17 September	23 September	124,000	100,000	30 August 1933		100,140	91,000	92
1933									
1934									
1935									
1936	21 September	6 October	98,000		15 June 1937			80,750	82
1942[a]	27 September	3 October	8,000	81,750[b]		73	7,921		99
1943									
1944							172	80,190	
1945									
1946	3 October	14 October	46,368				666	23,833	51
1947	23 September	6 October	149,400		18 August 1948		207	131,257	88
1948	16 September	11 October	516,550		26 July 1949		1,144	413,772[c]	
1949	22 September	22 September	4,895		9 March 1951		152	4,043	83
1950									
1951			32,535	250,000	3 February 1953		77	2,625	1
1952				680,450		1,087	159,983	186,019	51
1953									
1954									
1955	16 September	26 September	35,133		14 April 1956	5,725		33,758	
Mean	22 September	3 October	22,079	45,06	11 September	1,034	43,002	7,920	75

[a] No spawning or production for years 1937–41.

[b] Fry received.

[c] Reared at Carson National Fish Hatchery.

1946, when about 68% of the 1944 brood were released as yearlings; all 1949 and 1951 broods were also released as yearlings. Production was almost totally lost in 1952 to what was then believed to be a viral disease and was undoubtedly infectious hematopoietic necrosis (IHN; Cox 1952). Because of the poor adult return and the problems with disease in rearing the fish to yearlings, the program was abandoned in 1955, when the remaining juveniles were transferred to Carson NFH, where they all died.

Coho Salmon

Initial attempts to rear coho salmon with the native, late-running stock were made in 1919 and 1922 (Table 6). Attempts in 1930 and in the 1950's involved early-running stocks native to the Quinault, Quilcene, and Dungeness rivers of Puget Sound, Washington, as well as a native Toutle River stock. The Toutle River stock was considered responsible for establishing a successful run in 1956. In 1957 and 1958, eggs from Little White Salmon NFH were shipped to Willard NFH for incubation, after which the fry were returned for rearing. Additional eggs of the Toutle River stock were received from Eagle Creek NFH in 1962 and Bonneville State Fish Hatchery (SFH) in 1963.

Initially, these fish were released in their first summer; later, they were usually released as yearlings in February or March (Table 6). Fish reared at Little White Salmon NFH were also shipped to Spring Creek, Eagle Creek, Carson, and Willard NFH's for finishing and distribution; others were released in the Columbia, Snake, Klickitat, and John Day rivers. Part of the production from Willard NFH for the 1954 (231,571), 1957 (1,965,128), 1958 (562,590), and 1964 (12,210) broods was also released in the Little White Salmon River.

Miscellaneous Species

Also reared at Little White Salmon NFH were spring chinook salmon, three forms of rainbow trout (steelhead, rainbow, and Kamloops), cutthroat trout (*Oncorhynchus clarki*), and brook trout (*Salvelinus fontinalis*; Table 7). These fish came from various sources, and the resulting production was released in streams and lakes throughout the Columbia River basin. The 1956 and 1957, spring chinook salmon broods were released in the Wind River. Some of the Kamloops trout were shipped to New Hampshire, New York, and South Dakota.

Late Years—1965–1985

Although 1965–85 saw no major changes to the facility, numerous moderate improvements were made. In the mid-1960's, a power crowder and lifts were installed to facilitate handling adults. In 1974, the fish ladder and barrier dam were modified, and a flood wall was constructed. Throughout the 1970's, improvements and additions were made in the delivery, reuse, and treatment of the water supply.

Spawning techniques did not change, but beginning in the early 1970's the eggs were handled and incubated differently. The females were spawned into a colander, allowing the ovarian fluid to be discarded. The eggs from three or more females were placed in one bucket and fertilized with sperm from two or more males.

The eggs were washed and placed either in baskets in deep wooden troughs or in a 16-tray vertical incubator. In 1967, a water reuse system and a heating system were installed and used to incubate eggs. The reuse system consisted of three 24.4 × 2.4 m concrete ponds converted to biofilters, using rock and oyster shells as filter media. With this system, feeding of fall chinook salmon could begin in late December instead of February or March, and the system capacity of 1,600 gpm of 11.1° C water allowed their release in late June at 250/kg rather than 450/kg.

The conversion of incubation equipment had begun in 1965, when four 16-tray vertical Heath incubators were purchased. These incubators each held 480,000 chinook salmon eggs, used 20 gpm, and occupied 1.49 m^2 of floor space, as compared to 450,000 eggs held in 1 1/2 hatching troughs that used 27 gpm and occupied 3.34 m^2 of floor space. The conversion to Heath incubators was completed in 1976.

Fall Chinook Salmon

After 1964, fall chinook salmon spawning began significantly later in the year (t = 9.219, $P < 0.001$; Figs. 1 and 4). Previously, spawning began as late as 24 September; after 1967, this was the earliest that spawning began. Spawning also extended later into fall during this period than in earlier years.

Table 6. *Coho salmon* (Oncorhynchus kisutch) *spawning and production at Little White Salmon National Fish Hatchery, 1916–64.*

Brood year	Spawning		Egg take	Eggs transferred		Date released			Fish Released				Survival
	Start	End		Shipped	Received	Start	End	Mean	Number (kg)	LittleWhite Salmon River	Various	Total	(%)
1919	2 December	2 December	27,000			12 May 1920	12 May 1920	12 May 1920		22,050		22,050	82
1920													
1921													
1922	28 November	12 December	15,000			14 April 1923	14 April 1923	14 April 1923			9,000	9,000	60
1930						Unknown	Unknown	Unknown		96,000		96,000	
1950[a,c]					38,420[b]	9 May 1952	9 May 1952	9 May 1952	55	29,644		29,644	
1951					50,940	27 April 1953	27 April 1953	27 April 1953	64	27,762		27,762	54
1952													
1953	3 November	3 November	5,280			28 January 1954	28 January 1954	28 January 1954		4,990		4,990	95
1954	22 November	22 November	21,915		250,050	16 February 1956	16 February 1956	16 February 1956	86	255,218		255,218	94
1955					400,000	20 March 1957	20 March 1957	20 March 1957	82	351,166		351,166	88
1956					1,042,156	25 March 1957	23 October 1957	7 May 57	778		992,613	992,613	95
1957	17 October	6 December	792,448	732,825	728,000	10 December 1958	13 February 1959	30 December 1958	126	655,525		655,525	90
1958	14 October	21 November	713,647	713,647	671,994[b]	4 November 1959	11 February 1960	23 December 1959	121	561,479		561,47	
1959	8 October	27 November	829,700			20 October 1960	13 February 1961	9 December 1960	99	501,363	130,180	631,543	76
1960	14 October	9 December	1,654,786	10,000		23 February 1961	13 February 1962	10 June 1961	183	456,605	934,314	1,390,919	85
1961	11 October	8 December	459,950	10,000	1,969,979[b]	19 March 1962	6 February 1963	4 February 1963	119	2,290,559	10,000	2,300,559	91
1962	8 October	27 November	7,266,935	998,730	471,375	21 February 1963	31 March 1964	27 September 1963	207	2,683,420	2,350,395	5,033,815	81
1963	23 October	17 December	924,700		2,029,200	22 December 1964	22 December 1964	22 December 1964	110	2,760,650		2,760,650	85
1964	16 October	9 November	7,881,800	3,164,200		28 August 1965	16 October 1966	16 November 1965	79	939,800	2,064,180	3,003,980	64
Mean	26 October	28 November	1,715,264	938,234	710,246	1 September	11 December	2 October	163	775,749	927,240	1,066,289	81

[a] No spawning for years 1923–49.
[b] Fry received.
[c] No production for years 1931–49.

Table 7. *Production of miscellaneous species at Little White Salmon National Fish Hatchery, 1916–64.*

Brood year	Eggs received	Source[a]	Fish released		
			Date	Little White Salmon River	Various
Spring chinook (*Oncorhynchus tshawytscha*)					
1916	66,000	McKenzie River (Oreg.)	24 July 1917	44,500	
1925	500,000	Salmon River (Id.)	Unknown		
1944	28,315[a]	Carson NFH	15 October 1945	22,252	
1956	217,195	Bonneville Dam	17 November 1957		188,522
1957	143,852	Bonneville Dam	13 October 1958		132,489
Steelhead (*Oncorhynchus mykiss*)					
1925	95,000	Applegate (Oreg.)	24 July 1925	12,050	81,00
1926	50,000	Applegate(Oreg.)	14 June 1926		46,975
1927	140,000	Bonneville and Clackamas SFH	7 July 1927	18,000	68,000
1945	36,929	Carson NFH	15 December 1945	1,970	25,300
Rainbow trout (*Oncorhynchus mykiss*)					
1927	54,000	Bonneville SFH			
1956	379,550		17 April 1958		334,420
1957	22,545		2 July 1959		15,553
Brook trout (*Salvelinus fontinalis*)					
1925	200,000	Washington Fish Commission	25 May 1926		190,300
1926	105,000	Clackamas SFH	29 April 1927		65,000
1927	115,000	Clackamas SFH	28 June 1928		23,000
1928	206,000	Clackamas SFH	25 May 1929		181,000
Cutthroat trout (*Oncorhynchus clarki*)					
1932	100,000	Clackamas SFH	10 January 1933		82,500
Kamloops trout (*Oncorhynchus mykiss*)					
1956	1,846,359	Diamond Lake (Oreg.)	1 August 1957		599,284

[a] NFH = National Fish Hatchery; SFH = State Fish Hatchery.
[b] Fry received.

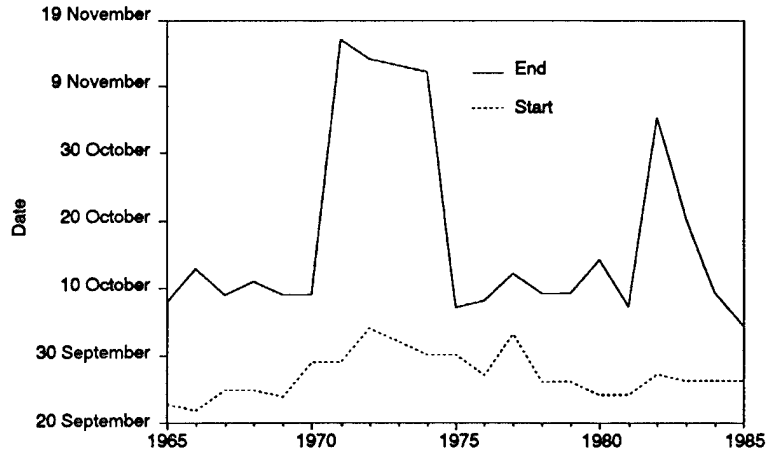

Fig. 4. Spawning time of fall chinook salmon at Little White Salmon National Fish Hatchery, 1965–85.

The annual egg take from 1965–85 was less than half that of earlier years (Tables 1, 2, and 8). In fact, the largest egg take of 17.5 million in 1966 was only about 1 million greater than the annual average from 1896 to 1964. Because of the reduced egg take, there was only one major shipment of eggs; in 1971, 505,000 eggs were transferred to a hatchery on Puget Sound. Substantial numbers of eggs were received, however, so that the eggs received exceeded the egg take in 11 of the 21 years. Before 1970, the eggs were from the same Bonneville Pool Hatchery Stock, but eggs after 1970 came from Eagle Creek, Bonneville, Big Creek, Cascade, Oxbow, and Abernathy hatcheries, all of which reared Lower River Hatchery Stock (Howell et al. 1984).

Time of release remained relatively consistent, with the mean date about 1 month later than in the years before 1965 (Fig. 5). Except in 1971, when most fish were released on 26 April, releases took place between mid-May and late June. This relatively consistent time of release resulted in minimal variation in size at release; about two-thirds of the fish released were between 200 and 285/kg.

Thirteen percent fewer fish were released from 1965 to 1984 than from 1916 to 1964 (Tables 2 and 8). Of the fish released, 56% were progeny of adults that had returned to the Little White Salmon NFH, 25% were from Spring Creek NFH, and 19% were from Lower River Hatchery Stocks. Considering the declining egg take, relatively large numbers were released elsewhere. Some of these fish were used in various research studies, but large numbers were also released in the Warm Springs (1966 and 1967 brood years), Willamette (1967 and 1968 brood years), and Wind (1967 brood year) rivers or transferred to Bonneville (1968, 1969, 1975, and 1980 brood years) and Spring Creek (1980 brood year) hatcheries.

Survival from egg take to release declined significantly, from 89% in 1916–64 to 76% in 1965–84 ($t = 4.832$, $P < 0.01$; Tables 2 and 8). From 1916–64 to 1965–84, survival of eggs declined slightly, from 93% to 90%, whereas juvenile survival declined significantly, from 95% to 85% ($t = 3.666$, $P < 0.01$). Rearing the fish to a larger size contributed to this

Table 8. *Fall chinook salmon* (Oncorhynchus tshawytscha) *production at the Little White Salmon National Fish Hatchery, 1965–85.*

Brood year	Egg take	Eggs transferred		Fish released				Salmon (%)
		Shipped	Received	Number (kg)	Little White Salmon River	Various	Total	
1965	9,600,000	25,000	565,200	306	8,627,280	70,650	8,697,930	86
1966	17,500,000			413	10,086,120	511,500	10,597,62	61
1967	15,761,800			324	7,791,384	3,169,332	10,960,716	70
1968	4,680,000		7,987,894	251	7,351,343	1,197,573	8,548,916	69
1969	9,721,700		4,377,900	225	6,695,384	396,141	7,091,525	50
1970	9,745,777		5,726,992	406	10,435,992	227,600	10,663,592	87
1971	14,377,735	505,000		281	12,411,940	2,950	12,414,890	89
1972	8,519,419		6,196,877	269	13,171,329		13,171,329	90
1973	4,349,715	5,000	11,386,257	211	10,525,857	506,004	11,031,861	70
1974	9,128,808		12,152,800	268	15,485,112	2,010	15,487,122	73
1975	7,673,568		14,244,487	225	15,547,382	586,000	16,133,382	74
1976	10,318,269		4,053,430	265	11,570,511	5,195	11,575,706	81
1977	8,303,567		12,782,439	196	14,373,226	16,061	14,389,287	68
1978	7,720,000		10,010,351	243	11,408,648	26,219	11,434,867	64
1979	4,777,994		7,497,500	233	8,724,047	1,048,838	9,772,885	80
1980	5,211,618		5,974,362	214	9,215,733	1,220,504	10,436,237	93
1981	3,286,636		7,605,325	205	8,038,498	53,331	8,091,829	74
1982	5,107,635		5,268,722	201	8,430,082		8,430,082	81
1983	2,758,919		5,915,650[a]	174	6,849,023		6,849,023	79
1984	1,792,629			242	1,608,000		1,608,000	90
1985	392,760			542		361,925	361,925	
Mean	7,653,740	25,476	5,797,437	251	9,445,090	447,706	9,892,796	76

[a] Includes 497,947 fry.

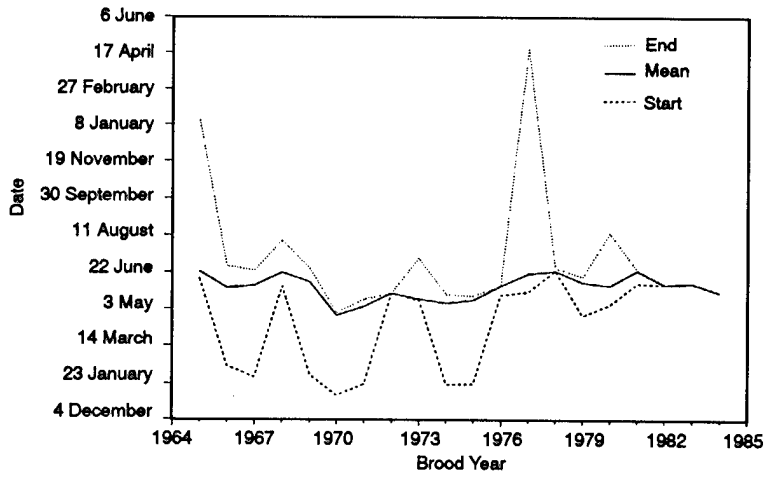

Fig. 5. Average time of release of juvenile fall chinook salmon from the Little White Salmon National Fish Hatchery, 1965–84.

increased loss, from gill, enteric redmouth, and cold-water diseases.

The stock–recruitment relation indicated a poor rate of return for fish released from 1965 to 1983 (Fig. 6) and, as in previous years, was not correlated with rate of harvest or escapement in the Columbia River. The stock–recruitment ratio of the 1914–81 broods released between 8 March and 28 April was 1.605, significantly higher than the 0.895 for fish released from 4 May to 25 June (t = 3.749, $P < 0.001$). After 1939 and the construction of Bonneville Dam, the stock–recruitment ratio was not significantly different among fish released before 1 May (1.205), after 1 May (0.742), or over an extended period (1.018). However, the survival of fish in the hatchery declined significantly, from 91% for fish released before May to 77% for fish released after 1 May (t = 3.207, $P < 0.001$). In terms of size of fish at release for 1939–81, the stock–recruitment ratio declined significantly, from 1.390 for fish released when smaller than 970/kg to 0.666 for fish released when larger than 330/kg (t = 2.506, P = 0.016). Because of the low return and the low contribution to the commercial or sport harvest, production of this stock was discontinued in 1985 by transferring the surviving juveniles to Klickitat SFH (Wahle and Vreeland 1979; Vreeland 1985).

Coho Salmon

By 1965, a dependable run of Toutle River coho salmon stock was established (Table 9). Spawning usually began during the last week of October and was completed by mid-November. The average annual egg take from 1965 to 1985 was larger than the maximum annual egg take in all the previous years (Tables 6 and 9). Increasingly larger numbers of eggs were moved to Willard NFH, until finally the Little White Salmon facility began serving its

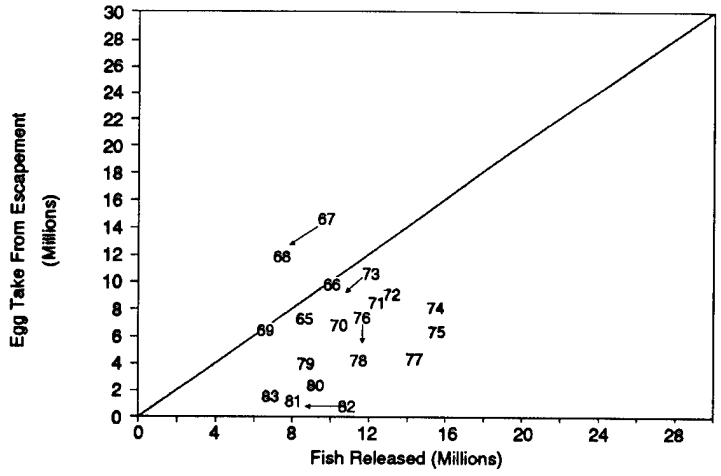

Fig. 6. Stock–recruitment of fall chinook salmon to Little White Salmon National Fish Hatchery, 1965–83.

Table 9. *Coho salmon* (Oncorhynchus kisutch) *spawning and production at Little White Salmon National Fish Hatchery, 1965–85.*

Brood year	Spawning			Eggs transferred		Date released			Fish released				Survival (%)
	Start	End	Egg take	Shipped	Received	Start	End	Mean	Number /kg	Little White Salmon River	Various	Total	
1965	15 October	17 November	16,101,800	13,450,000	1,280,000	26 February 1966	25 April 1967	6 August 1966	181	675,900	1,209,200	1,885,100	48
1966	31 October	15 November	16,844,000	13,504,400	60,000	10 February 1967	22 April 1968	1 November 1967	82	743,597		743,597	36
1967	24 October	17 November	20,126,023	15,512,456		21 April 1969	22 April 1969	21 April 1969	44	648,226		648,226	14
1968	23 October	12 November	5,603,000	4,740,650	926,261	15 April 1970	20 May 1970	7 May 1970	42	490,290	158,200	648,490	36
1969													
1970													
1971	26 October	7 December	8,100,000		761,840			15 April 1973	57	607,707		607,707	66
1972	24 October	17 November	549,500										
1973	24 October	12 November	2,622,640					15 January 1974	3,263		1,531,504	1,531,504	
1974													
1975			13,644,000	4,695,889	225,700	15 April 1976	15 August 1976	16 April 1976	703	218,100	1,500	219,600	8
1976[a]	26 October	17 November	13,026,000	13,026,000									
1977	25 October	16 November	1,302,000	1,302,000									
1978	26 October	17 November	5,281,000	5,281,000									
1979	24 October	18 November	6,003,000	6,003,000									
1980	27 October	21 November	1,761,012	1,761,012									
1981													
1982	21 October	3 November	6,207,205	6,207,205									
1983	19 October	23 November	1,310,764	1,310,764									
1984	31 October	26 November	7,029,210	7,029,210									
1985	28 October	18 November	9,230,618	9,230,618									
Mean	24 October	17 November	7,925,987	7,361,015	406,725	18 March	19 June	21 May	622	161,134	138,114	299,249	35

[a]Transferred 1976–85 brood years to Willard National Fish Hatchery for rearing.

present function as an egg-taking station for Willard NFH. Eggs were also shipped to Entiat, Winthrop, Leavenworth, Carson, and Coleman NFH's; Washougal SFH; and California, Connecticut, Idaho, New Hampshire, and Pennsylvania. In 1975, 770,790 eggs were also shipped to Korea. Eggs and fry were received from Eagle Creek and Leavenworth NFH's and Klaskanie SFH.

Production releases of coho salmon into the Little White Salmon River usually took place in late April to mid-May when the fish were yearlings (Table 9). Releases of age-0 fish were made in the Grand Ronde, Umatilla, John Day, Klickitat, and Hood rivers. After 1965, fish were reared to a larger size, resulting in a lower survival rate in the hatchery than from 1950–64.

Spring Chinook Salmon

The spawning of spring chinook salmon first occurred in 1967, when fish of unknown origin returned to the Little White Salmon River (Table 10). They could have been strays or descendants of fish released earlier from the McKenzie River (1916 brood year), Salmon River (1925 brood year), or Carson stock reared at Willard NFH (1964 brood year). In the following years, fish were released in the Little White Salmon River from Willamette stock reared at Eagle Creek NFH (1966, 1967, and 1971 brood years) and South Santiam SFH (1974 brood year), Klickitat River stock (1966, 1968, and 1974 brood years), and Carson stock (1968, 1970, 1972, 1973, 1974, and 1985 brood years). Although at least four different stocks of spring chinook salmon were released, the present stock is considered a derivative of the Carson stock (Howell et al. 1984.) The mixture of stocks may have contributed to the erratic and extended spawning periods, but hatchery personnel also had difficulty separating the spring and fall races of chinook salmon (Johnson, personal communication). Spawning—although previously not begun until late August and continuing until early November—has stabilized since 1980; it now usually occurs from mid-July to early September (Table 10). Since 1982, adults have been held indoors and exposed to advanced photoperiod to induce earlier spawning.

By 1974, the egg take was sufficient to allow transfer of eggs to other locations: Kooskia (1974 and 1975 brood years), Dworshak (1983 brood year), and Hagerman (1983 brood year) NFH's in the Snake River basin; Leavenworth (1974, 1977, 1978, 1979, 1980, and 1981 brood years), Winthrop (1975, 1976 brood years), and Entiat (1976 brood year) NFH's in the upper Columbia River; Klickitat (1977 brood year), Oxbow (1976 brood year), Toutle River (1977 brood year), Kalama Falls (1977 brood year), and Lewis River (1980 brood year) SFH's in the lower Columbia River; and the 1976 brood year to Oakridge SFH in the Willamette River basin. Small numbers of eggs were transferred in 1970 and 1972 for research purposes.

Fish were usually released as yearlings during April or early May at about 45/kg (Table 10). The primary exceptions to this were release of the entire 1972 brood year in January 1974 and partial release of the 1982–85 brood years from mid-May to late June of their first summer (a result of advanced spawning). All fish reared were released to the Little White Salmon River except for parts of the 1966 and 1977 brood years, which were transferred to the Klickitat River and Washington Department of Fisheries, respectively; small numbers were also used in a variety of research studies. The extended rearing of spring chinook salmon resulted in relatively poor survival in the hatchery. Most losses were caused by kidney, gill, and cold-water diseases.

Discussion

During the first 20 years of operation at Little White Salmon NFH, only fall chinook salmon were reared. The program was apparently successful because the egg take was about threefold higher from 1912 to 1917 than before. In 1917, 8,047 females were spawned, indicating a large escapement, considering the small size of the river, the inefficient methods used to capture adults, the release of most fish as fry, and the intense and largely unregulated commercial fishery in the Columbia River (Phinney 1976).

During the next 50 years, profound changes occurred in the operations of the hatchery. Propagation was expanded to include four other salmons—chum, coho, sockeye, and spring chinook—and various species of trout, many of which were obtained from outside the Columbia River basin. In addition, the fish were reared for increasingly longer periods. For most of this era, the fish were fed primarily salmon carcasses; it was not until the late 1950's that prepared diets were introduced.

After the closure of Bonneville Dam in 1938, the average egg take of fall chinook salmon declined about 44%. The average number of juveniles released in the Little White Salmon River from 1939

Table 10. *Spring chinook salmon* (Oncorhynchus tshawytscha) *spawning and production at Little White Salmon National Fish Hatchery, 1965–85.*

Brood year	Spawning		Egg take	Eggs transferred		Date Released			Fish released				Survival (%)
	Start	End		Shipped	Received	Start	End	Mean	Number /kg	Little White Salmon River	Various	Total	
1965													
1966					550,500[a]	23 August 1967	8 April 1968	5 December 1967	115	156,030	185,910	341,940	
1967	24 August	1 September	49,300		259,000	21 April 1969	22 April 1969	22 April 1969	68	265,143	744	265,887	86
1968	21 August	8 October	192,000		521,000	1 July 1969	14 April 1970	10 April 1970	48	456,700	3,250	459,950	68
1969	19 August	22 September	1,023,600			1 December 1970	2 April 1971	2 April 1971	44	696,883	50	696,933	68
1970	22 July	24 September	350,194	10,000	1,123,196	1 November 1972	1 November 1972	1 November 1972	44	576,322		576,322	39
1971	29 July	8 November	1,232,264		413,128	1 February 1973	1 April 1973	1 April 1973	33	575,932	110	576,042	35
1972	12 July	22 October	628,466	43,950	1,070,615	1 January 1974	1 January 1974	1 January 1974	46	1,063,895		1,063,895	65
1973	26 July	4 September	350,262		846,640	1 May 1974	1 April 1975	1 January 1975	35	1,007,455	1,459	1,008,914	84
1974	24 July	24 September	110,440	1,727,335	2,804,498	1 April 1976	1 April 1976	1 April 1976	44	571,747	1,320	573,067	48
1975	22 July	24 September	2,817,868	1,560,497		1 May 1976	2 May 1977	2 May 1977	35	693,990	1,610	695,600	56
1976	11 August	8 October	719,374	3,144,574		13 September 1977	4 April 1978	4 April 1978	42	621,116	2,475	623,591	40
1977	17 August	14 September	6,642,634	3,763,405		10 April 1979	26 April 1979	23 April 1979	44	790,401	153,254	943,655	33
1978	15 August	15 September	4,542,221	2,981,980		1 June 1979	16 April 1980	21 February 1980	55	734,790	3,084	737,874	47
1979	17 August	10 September	1,919,099	702,895		20 April 1981	20 April 1981	20 April 1981	42	645,680	1,020	646,700	53
1980	22 July	2 September	1,573,828	282,860		28 October 1981	20 February 1982	3 February 1982	37	683,682		683,682	53
1981	16 July	4 September	5,632,264	4,004,708		16 March 1982	15 April 1983	8 April 1983	42	960,783	1,000	961,783	59
1982[b]	20 July	2 August	1,454,448			15 January 83	24 June 1984	30 April 1984	161	688,068		688,068	47
1983	18 July	2 September	6,167,368	2,632,105					55	2,589,339		2,589,339	73
1984	23 July	20 August	1,286,722						48	1,078,161		1,078,161	84
1985	23 July	5 August	1,809,684		1,200,000				77	1,948,342	500,000	2,448,342	81
Mean	31 July	14 September	2,236,949	1,895,846	676,044	17 November	19 April	29 March	56	840,223	61,092	882,987	59

[a] Includes 250,000 fry.

[b] No data available for years 1983–85.

to 1964 (12,071,000 eggs) remained almost the same as it was from 1916 to 1938 (12,044,000), however, because shipments of eggs were reduced, and releases were supplemented with fish reared at Willard NFH.

Since 1965, the operations of Little White Salmon NFH have been relatively consistent. Efforts to rear sockeye salmon, chum salmon, and trout were discontinued. Instead, efforts centered on rearing spring and fall chinook salmon and on serving as a coho salmon egg-taking facility for Willard NFH. Time of release stabilized so that fall chinook salmon were usually released in mid-June of their first summer, and spring chinook salmon were released in April as yearlings. Unfortunately, the run of fall chinook salmon, which was reported to have "filled the river for a month" 90 years earlier, declined to the point where attempts to maintain the strain were discontinued, and efforts shifted to rearing Bonneville, upriver bright fall chinook salmon, hatchery stock.

The declining condition of the fall chinook salmon stock was manifested by declining egg take, survival, and stock–recruitment ratios (Table 8; Fig. 6). Four marking studies also showed a progressive decline in escapement to the hatchery and in harvest in the Columbia River fishery (Table 11). It is particularly striking that more marked fish from the 1915 and 1919 broods were recovered in the commercial fishery than from the 1964 or 1978–80 broods, even though >10 times more fish were released in the later studies. Considering the relative effort expended in sampling the commercial fishery in the two periods, the difference becomes even more striking.

The decline of the Little White Salmon River stock of tule fall chinook salmon cannot be attributed to any single factor. Apparently, the construction of Bonneville Dam, introduction of different stocks, and longer juvenile rearing were all contributing factors. The flooding of rearing ponds by closure of Bonneville Dam resulted in release of juveniles <970/kg until new facilities were completed in 1947. In addition to mortality from passage through the reservoir and dam, releasing juveniles at this small size undoubtedly reduced their probability of survival. The magnitude of these combined effects is clearly exhibited in the extremely poor stock–recruitment ratios for the 1939–42 brood years and record low egg takes from 1943 to 1946 (Table 2; Fig. 3).

The importation of stocks from increasingly distant areas and subsequent intermingling with the native fish also probably contributed to the decline. The lack of sufficient adult return to bring the hatchery up to its rearing capacity must have contributed to the decision to import the different stocks. Reisenbichler (1988) determined that the recovery rate of hatchery-reared coho salmon was negatively related to the distance they were released from their native stream. The importation and possible release of nonnative stocks occurred 4 times (1901, 1922, 1926, and 1941) in the first 50 years of operation and 31 times in the past 38 years. In fact, from 1968 to 1983, 51% of the fall chinook salmon released in the Little White Salmon

Table 11. *Release and recovery data for marking studies conducted on fall chinook salmon (*Oncorhynchus tshawytscha*) reared at Little White Salmon National Fish Hatchery.*[a]

Fish released and recovered	Brood years			
	1915–19	1956–58	1964	1978–80
Released				
Number	74,000	3,676,420	797,345	854,300
Size (no./kg)	660	313	390	218
Date	Jul, Aug	May–February	June	June
Recovered				
Hatchery	17	688	37	38
Columbia River fishery	32		13	29
Released–Recovered (× 1,000)				
Hatchery	0.23	0.19	0.05	0.04
Columbia River fishery	0.43		0.02	0.03
Stock–recruitment ratio	0.95	0.86	1.12	0.36

[a] Data from Rich and Holmes 1929; Cox 1956, 1957, 1958, 1959, 1960; Wahle and Vreeland 1979; Vreeland 1985.

River were not native to the system. The effect of these introductions on the native stock is illustrated by the significant change in spawning time, from a mean of 20 September in the years before 1963 to a mean of 27 September from 1964 to 1985.

The introduction of different stocks of tule fall chinook salmon, in conjunction with the sockeye salmon and chum salmon stocks from Alaska and Puget Sound populations, probably introduced pathogens to the Little White Salmon NFH. Records through the 1940's do not mention any excessive losses to diseases; instead, they comment that the hatchery was free of diseases. In the 1950's, the mention of diseases increased, and juvenile losses became progressively more common. Compounding the disease problem was the decision to rear fish for longer periods. Before 1953, fall chinook salmon were invariably released before mid-May; thereafter, they were generally released later, and some were held for release the following year. This extended rearing resulted in juvenile survival declining significantly from 1916–64 to 1965–84.

Evidence to support the decision to release fall chinook salmon in mid-June to correspond with high flow rates is lacking. After the closure of Bonneville Dam, the stock–recruitment ratios of brood years released before 1 May were higher than those released later. As the survival of the broods in the hatchery declined significantly when reared for the longer period, it would appear that the earlier release of fish would have been more effective.

Although well intentioned, the efforts to perpetuate a stock of salmon led instead to its demise. It would be convenient to solely blame the construction and operation of Bonneville Dam for causing the extinction, but in the 30 years from 1939 to 1968, the stock–recruitment ratio was >1 in each of 17 years, and the egg take exceeded 11 million on 16 occasions. Therefore, the causes for the extinction of this stock of fall chinook salmon apparently included the introduction of different stocks, which altered their genetic fitness and introduced diseases, and the management decision to rear fish longer, which decreased their survival both in the hatchery and after release.

As a postscript, the decision to switch to the "bright" stock of fall chinook salmon in 1985 received a setback in May 1987, when the entire year's production was destroyed because of an outbreak of IHN.

Acknowledgments

We thank D. Diggs, D. Leith, and J. Mullan for their constructive reviews of the manuscript. Review and comments by B. Cox, H. Johnson, and A. Kemmerich, who were Little White Salmon NFH manager (1947–60), Little White Salmon NFH biologist (1953–72), and Columbia River Program Director (1938–60), respectively, were particularly helpful. J. Hall-Griswold designed the cover illustration.

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